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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a **PROVISIONAL APPLICATION FOR PATENT** under 37 CFR 1.53(c).

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TITLE OF THE INVENTION

SCANNING METHOD AND APPARATUS

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METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION

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X A check is enclosed to cover the filing fee for a SMALL ENTITY = **$ 80**
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X No.
Yes, name of U.S. Government agency and the Government contract number are:

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SCANNING METHOD AND APPARATUS

FIELD OF THE INVENTION

The present invention relates to a scanning method and apparatus, of particular but by no means exclusive application in scanning fibre microscope and scanning fibre endoscopes.

BACKGROUND OF THE INVENTION

One existing scanning technique employs a resonant cantilever in order to achieve the high frequency scanning of an optical fibre tip, as a compact alternative to resonant mirror/galvonometer scanners. The high frequency or X scan is then combined with a slow or Y scan to produce a standard raster scanning pattern. The slow scan is usually not resonant and can have a sawtooth function, with relatively rapid retrace.

Typically in existing systems, the Y mechanism is in tandem with the X deflection system and has similar length. However, as demand increases for ever more compact scanners there is a need to develop a combined XY scanner of shortest possible length. If the fibre can itself be deflected in both X and Y directions, as a symmetrical cantilever, the scanner is more compact. The problem is that for practical forces only resonant operation is feasible. For this reason modulated circular patterns have been developed, such as is disclosed in US Patent No. 6,294,775 (Seibel and Furness).

US Patent No. 6,294,775 discloses a system in which a fibre tip is typically moved in a circle or ellipse, the radius of which is then modulated so that an area is progressively scanned. Suitably phased X and Y drives can produce the circular motion, effectively resonant in both X and Y directions. However, the modulation of the radius of the scanning circle or ellipse results in a large

variation in scanning speed, and a singularity at the centre of the field. This scan pattern is very different from a raster scan, so the resulting circular pattern requires image processing, creating interface problems with standard systems.

SUMMARY OF THE INVENTION

The present invention provides, therefore, a method of scanning a light transmission means having an exit tip, comprising moving said tip in an elliptical pattern while varying the eccentricity of said elliptical pattern, whereby a portion of said elliptical pattern having a centre on the minor axis of said elliptical pattern approximates a raster pattern.

Preferably the eccentricity is varied by varying the length of one axis of said elliptical pattern. More preferably the eccentricity is varied by varying the length of the minor axis of said elliptical pattern

Thus, because the central portion of an ellipse (either to one side of the major axis or spanning the major axis) approximates a rectangle, especially when that portion is narrow in the direction of the major axis, as the eccentricity of the elliptical pattern is varied a scan pattern will result that approximates a raster pattern. Some barrel distortion will result, but this form of distortion can be tolerable or - if not - is relatively easily corrected by image processing. In any event, relative to the prior art modulation of radius technique, this distortion is small. The ellipse could even be a circle at its point of minimum eccentricity (that is, an ellipse with an eccentricity of zero), if - in certain applications - the resulting distortion were tolerable or correctable.

It should also be understood that the term light is used

above to include all forms of electromagnetic radiation.

Preferably the eccentricity is repeatedly varied between a minimum value and one. More preferably the eccentricity is repeatedly varied from a minimum value to one and then back to said minimum value, and said portion is centred on the centre of said elliptical pattern.

Preferably said elliptical pattern has a major axis and minor axis in the ratio of approximately two.

Preferably said method includes modulating said eccentricity by modulating the minor axis of said elliptical pattern between positive and negative extremes, so that said tip moves in both clockwise and counterclockwise directions in the course of a single complete scan.

Preferably said method includes driving said tip with an X drive parallel to the major axis of said elliptical pattern and with a Y drive parallel to the minor axis of said elliptical pattern, and synchronising at a constant phase to the X scan to allows interfacing to a standard raster display.

Preferably said Y drive is derived by synchronously switching a delayed version of said X drive.

For example, drive signals can be square waves, so any phase shifting can be accomplished by simple delay circuits.

Preferably said light transmission means is an optical fibre.

Preferably the method includes driving said light transmission means magnetically. More preferably the

method includes driving said light transmission means by means of a magnet attached to said light transmission means, wherein said magnet is magnetised axially and acted on by mutually perpendicular coils or windings.

In one embodiment, the light transmission means is provided with a coat of magnetic material. Alternatively, the light transmission means is located within a close-fitting magnetic tube.

These options permit the resonant frequency and length to be matched to design requirements.

The present invention also provides a scanning apparatus, comprising:

a light transmission means having an exit tip;

first and second drive means for resonantly driving said light transmission means in orthogonal directions;

wherein said first and second drive means are operable to move said tip in an elliptical pattern while varying the eccentricity of said elliptical pattern, whereby a portion of said elliptical pattern having a centre on the minor axis of said elliptical pattern approximates a raster pattern.

Preferably the eccentricity is varied by varying the length of one axis of said elliptical pattern. More preferably the eccentricity is varied by varying the length of the minor axis of said elliptical pattern

The invention also provides an optical fibre endoscope or microscope comprising a scanning apparatus as described above.

BRIEF DESCRIPTION OF THE DRAWING

In order that the present invention may be more clearly

ascertained, embodiments will now be described, by way of example, with reference to the accompanying drawing, in which:

Figure 1A is a schematic diagram of the start of an elliptical scan according to an embodiment of the present invention in which the scan commences clockwise;

Figure 1B is a schematic diagram of the scan of figure 1A just past its mid-point and now proceeding anti-clockwise;

Figure 1C is a schematic diagram of the data acquisition portion of one complete cycle of the scan of figure 1A;

Figure 2 is a schematic diagram of the Y drive signal used to produce the scan of figure 1A;

Figure 3 is a schematic diagram of the Y drive signal used to produce a scan according to another embodiment of the invention;

Figure 4 is a schematic diagram of the Y drive signal used to produce a scan according to further embodiment of the invention;

Figure 5 is a schematic circuit diagram of a scanning apparatus of the present invention; and

Figure 6 is a diagram of the coil driving mechanisms of the apparatus of figure 5.

DETAILED DESCRIPTION

An elliptical scan pattern according to one embodiment of the present invention is shown, soon after commencement, at 10 in figure 1A. In this figure (and in figures 1B and 1C), a broken curve indicates those portions of this scan where no data acquisition is occurring; a solid curve indicates data acquisition.

The scan traces out a first ellipse 12 with a major axis twice the length of its minor axis (that is, with an eccentricity of approximately 0.87).

When the scan reaches the top, central region of ellipse 12 (that is, at point 14 to the left of the minor axis) data acquisition is triggered and continues to a comparable point 16 to the right of the centre of the ellipse 12 at which data acquisition is stopped. Thus, data is acquired over an arc with a length approximately equal to the semi-major axis of the ellipse 12. Although this arc has some curvature, this does not lead to an excessive level of distortion if processed as though it were straight. In addition, it is possible by conventional means to process any image collected by this technique to remove that distortion (producing thereby an image with curved upper and lower sides).

The first ellipse 12 is completed when its lower, fly-back section is traced. During non-data acquisition portions generally, either a light signal can be received but be discarded, or the source of light can be switched off or obscured so that in fact no data is generated.

The scan then proceeds, but with a lower Y drive signal so that the next ellipse (whose initial portion 18 is indicated in the figure) has the same major axis as the first ellipse 12, but a smaller minor axis and hence greater eccentricity. Data is acquired between points 20 and 22, which are aligned vertically with, respectively, points 14 and 16 of first ellipse 12. The resulting data acquisition trace 24 is consequently displaced downwards relative to the first data acquisition trace 26, and has a smaller curvature.

The scan proceeds in this manner, with progressively decreasing Y drive signal, as shown in figure 1B at 30. Eventually, however, the Y drive signal equals or approximates zero and an essentially horizontal scan 32 results. The Y drive signal then reverses polarity and starts to increase while the X drive signal (essentially

an unmodulated square wave of constant maximum amplitude) remains as before. The minor axis of the traces now increases, and the next trace 34 commences.

However, as a consequence the successive ellipses are now traced in an anti-clockwise direction; data is now acquired in the lower (i.e. left to right) portion of each of these traces so that, throughout the scan, data is acquired left to right, and fly-back (that, with no data acquisition) is right to left.

Referring to figure 1C, eventually a complete, raster-like scan 40 is performed, after which the Y drive signal (by the end of the scan at its maximum amplitude) is switched in polarity to its original polarity and the process is repeated.

As mentioned above, the left to right or X drive signal is not modulated, but is conveniently a constant amplitude square wave that is also available to gate the Y drive signal. The Y drive signal is based on a standard raster scanner system signal with slow Y component, but the standard sawtooth signal is gated by a suitably delayed version of the X drive signal to produce the elliptical motion as discussed above. This Y drive signal is shown schematically at 50 in figure 2. As will be apparent from this figure, the envelope of this signal has a standard sawtooth form, but the Y drive signal is gated by the fast square wave X drive signal to produce the successive elliptical scans with progressively smaller then larger minor axes. Thus, the initial portion 52 corresponds to the clockwise scan portion discussed above by reference, in particular, to figure 1A. Eventually the essentially straight scan (scan 32 of figure 1B) is formed when the Y drive signal 50 is essentially zero at point 54. The polarity of the Y drive signal 50 is then changed and its magnitude increased through anti-clockwise portion 56

until a maximum amplitude 58 is reached, after which the whole sequence recommences. The amplitude of the next trace is maintained but is of reverse polarity so that a new clockwise scan 60 commences.

From the above discussion, it will be apparent that this modulation of the minor axis through positive and negative values produces a scan with no continuities at the centre of the field, unlike prior art approaches where the radius of the scan is modulated.

It will also be appreciated that an artefact of modulating the Y drive signal by means of the X drive signal is that each peak in the Y drive signal has an oblique rather than flat peak. This means that the elliptical scans will have some distortion, as the minor axis of each trace is changing in the course of that trace. This should generally be an insignificant effect, but if preferred, the Y drive signal 50 can be replaced with a signal in which each maximum is a square wave of progressively decreasing or increasing amplitude. Each successive ellipse would therefore be closer to an ideal ellipse. It is not expected, however, that the approximation represented by the trace of figure 2 would lead to any significant distortion to the ultimate raster scan or image.

A Y drive signal according to an alternative embodiment is shown generally at 70 in figure 3. In this embodiment, when a single complete scan is being completed (that is, after clockwise traces 72 and anti-clockwise traces 74 [cf. traces 52 and 56 of figure 2] have been completed), the system does not jump back to the original configuration shown in figure 1A. Rather than switching the polarity of the Y drive signal 70 and commencing a new clockwise scan, the Y drive signal from maximum 76 onwards is ramped downwards so that another sequence of anti-

clockwise traces 78 is performed. This is done by acquiring data during what was previously the fly-back period which, during the last anti-clockwise trace, resembles the first clockwise trace shown in figure 1A though in the opposite direction. Thus, by acquiring data during what would have been fly-back periods, a sequence of anti-clockwise traces 78 is performed and data is acquired. It will be appreciated that as a consequence successive complete raster scans alternate between left to right data collection (as shown, for example, in figure 1C) and right to left data collection.

In still another embodiment, the Y scan signal 80 (see figure 4) is always of one polarity but comprises a first sequence of clockwise traces 82 with decreasing amplitude followed by a second sequence of clockwise traces 84 with increasing amplitude. In this embodiment, the traces proceed essentially as described with respect to figure 1A until the essentially horizontal trace is performed after which the same sequence of traces is performed in reverse order. Data is acquired during this second set of traces during what was the fly-back periods of the first set of traces 82. Consequently, the first set of traces 82 have data acquired from left to right, while the second set of traces 84 have data acquired from right to left.

It will be appreciated, therefore, that these and other variants can be used according to the present invention to collect a complete set of data, according to a user's equipment or other requirements. Indeed, in some embodiments it may be acceptable or desirable that the raster scan comprise essentially the upper half of the complete scan shown in figure 1C or, indeed, some other portion thereof. It will be appreciated that the number of individual traces within any particular raster scan can be determined according to requirements and that the above embodiments are purely illustrative in this respect.

Figure 5 is a schematic circuit diagram of a scanning apparatus of the present invention, for performing the various scanning methods of the above described embodiment.

The apparatus includes a light transmission means in the form of optical fibre 90 that can be deflected in both X and Y directions as a symmetrical cantilever. It is the tip of this optical fibre 90 that, in resonant operation, describes the elliptical pattern detailed above. The optical fibre 90 delivers light from a suitable source (such as a laser or light emitting diode) downstream of the optical fibre 90 but omitted from this figure for the sake of clarity. The scanning apparatus including optical fibre 90 may form a portion of an endoscope, microscope or endomicroscope.

A forward portion of optical fibre 90 is located adjacent an X driving coil 92 and a Y driving coil 94, these coils arranged mutually perpendicularly. The optical fibre 90 is provided either with a magnet attached to the fibre adjacent to and acted on by the coils 92, 94 or, alternatively, by coating the optical fibre 90 with a magnetic material (including, for example, certain paints), so that the forces produced by these coils 92 and 94 can drive the optical fibre 90.

Located toward the rearward end 96 of the movable portion of optical fibre 90 is a piezoelectric X sensor 98 for producing a voltage according to the deflection of the optical fibre 90. The output of X sensor 98 is ultimately applied to the X driving coil 92, but is first phase adjusted by phase shifter 100 and amplified by signal processing amplifier 102. If the loop gain is sufficient and the phase correctly adjusted by phase adjuster 100, the resulting oscillation causes the tip of optical fibre

90 of the cantilever to vibrate in the X direction. The adjustable phase shifter 100 is included so that the frequency of oscillation can be suitably positioned on the mechanical resonance curve, and to compensate for any phase shift in the X sensor 98.

The amplifier 102 also performs some signal processing so that its output is a square wave of adjustable amplitude. This allows direct control of the vibration amplitude, and the square wave is also useful in the generation of the Y drive signal (see figures 2 to 4) for the Y driving coil 94.

The Y drive signal has a phase that is appropriate to obtain the elliptical motion described above. This is achieved with an adjustable delay 104 of the square wave used for driving the X driving coil 92. The required sweeping amplitude is obtained by using this signal to switch a standard Y sawtooth signal 106, as described above and illustrated in figures 2 to 4. This signal is then applied to the Y driving coil 94. The circuit also includes a switch 108 for switching the Y drive signal on or off.

Figure 6 is an end view (that is, viewed from right to left in figure 5) of the tip of optical fibre 90 and the X and Y driving coils 92 and 94. In this figure can also be seen the core 110 of optical fibre 90, as well as the magnet 112 attached to the optical fibre 90 so that the X and Y driving coils 92, 94 can drive optical fibre 90. The use of a magnet allows small adjustments to be made to the position of the magnet 112 on fibre 90 and thereby to the resonance condition of the fibre 90. Owing to the greater mass of magnet 112 (when compared with other embodiments such as a painted metallic coating), the driving coils 92, 94 can be relatively small, though at the expense of having a larger and more massive

fibre/magnet combination.

Modifications within the scope of the invention may be readily affected by those skilled in the art. For example, while, according to the present invention, eccentricity or minor axis are adjusted to achieve the scanning pattern, in some embodiments it may be desirable also to modulate the radius during operation. It is to be understood, therefore, that this invention is not limited to the particular embodiments described by way of example herein above.

Further, references above to prior art systems include no suggestion that such systems are common general knowledge.

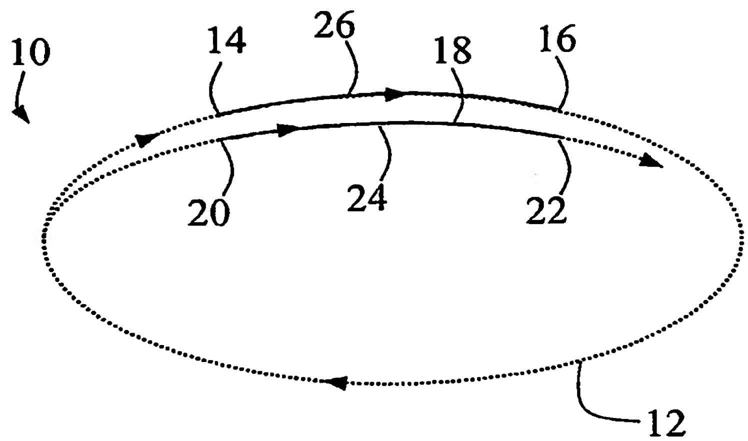

Figure 1A

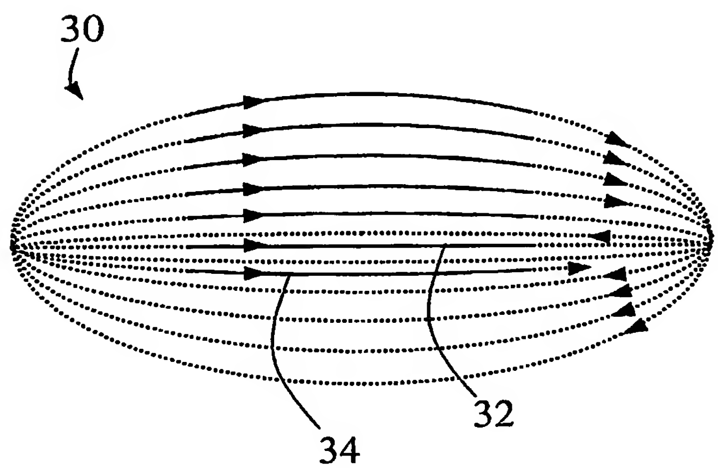

Figure 1B

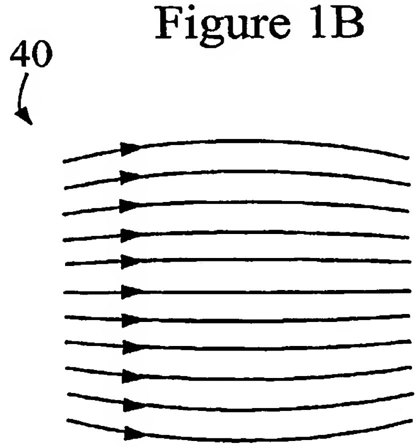

Figure 1C

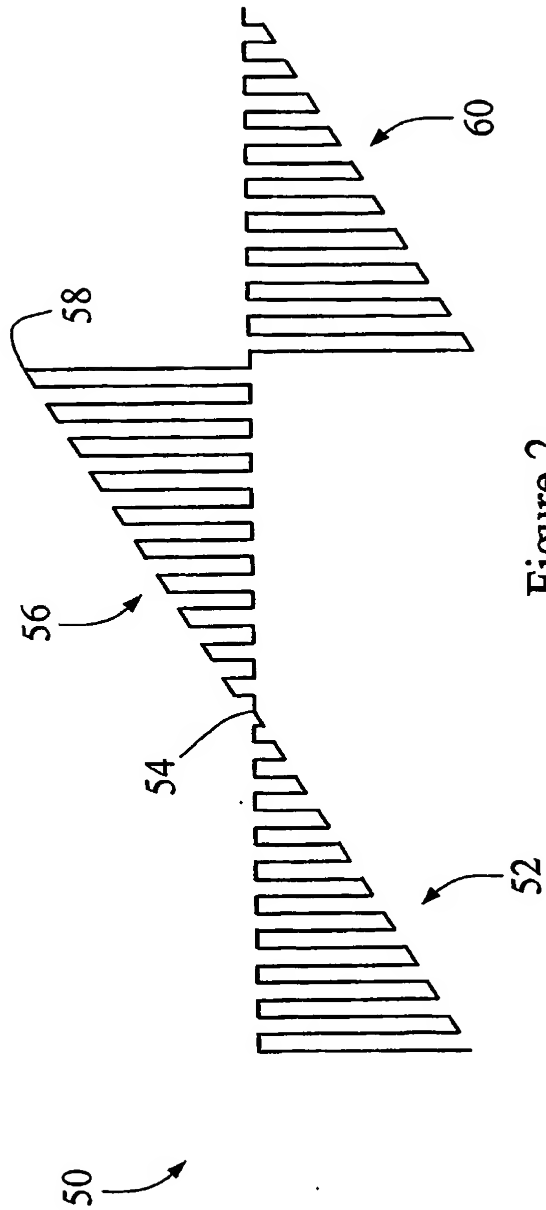

Figure 2

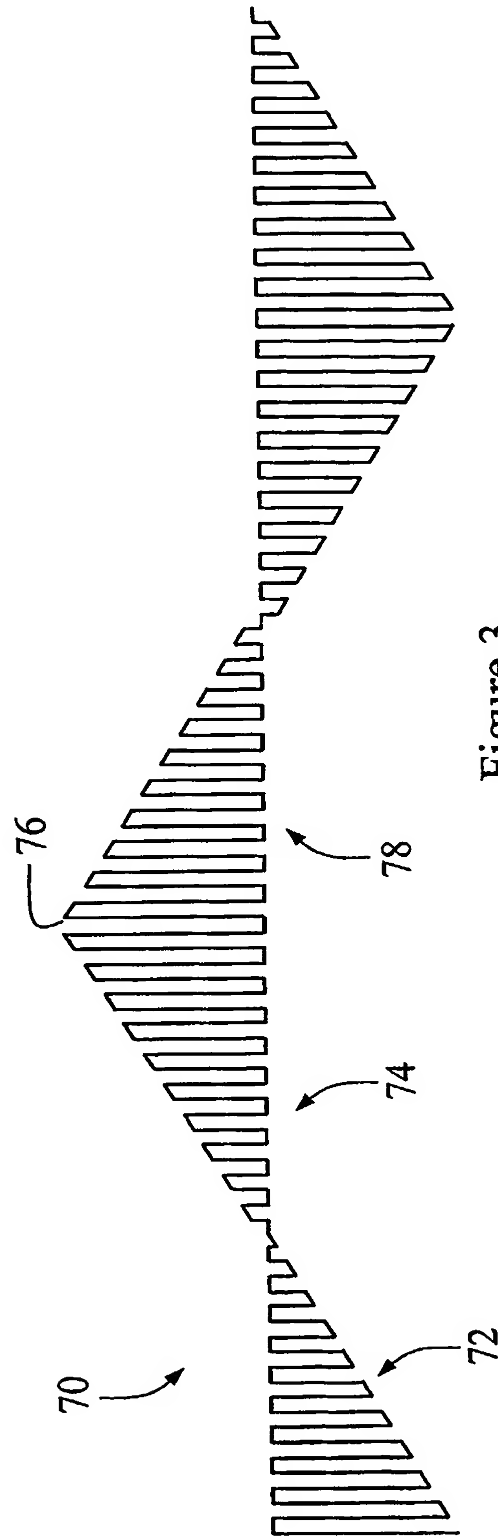

Figure 3

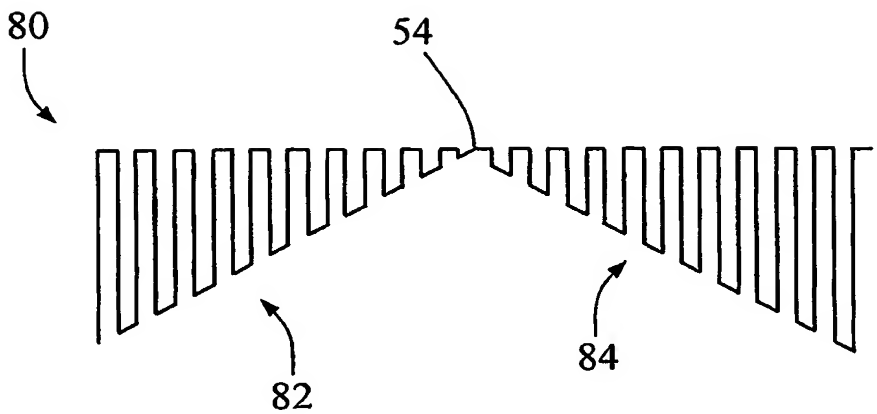

Figure 4

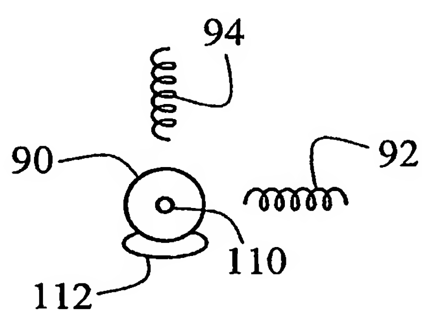

Figure 6

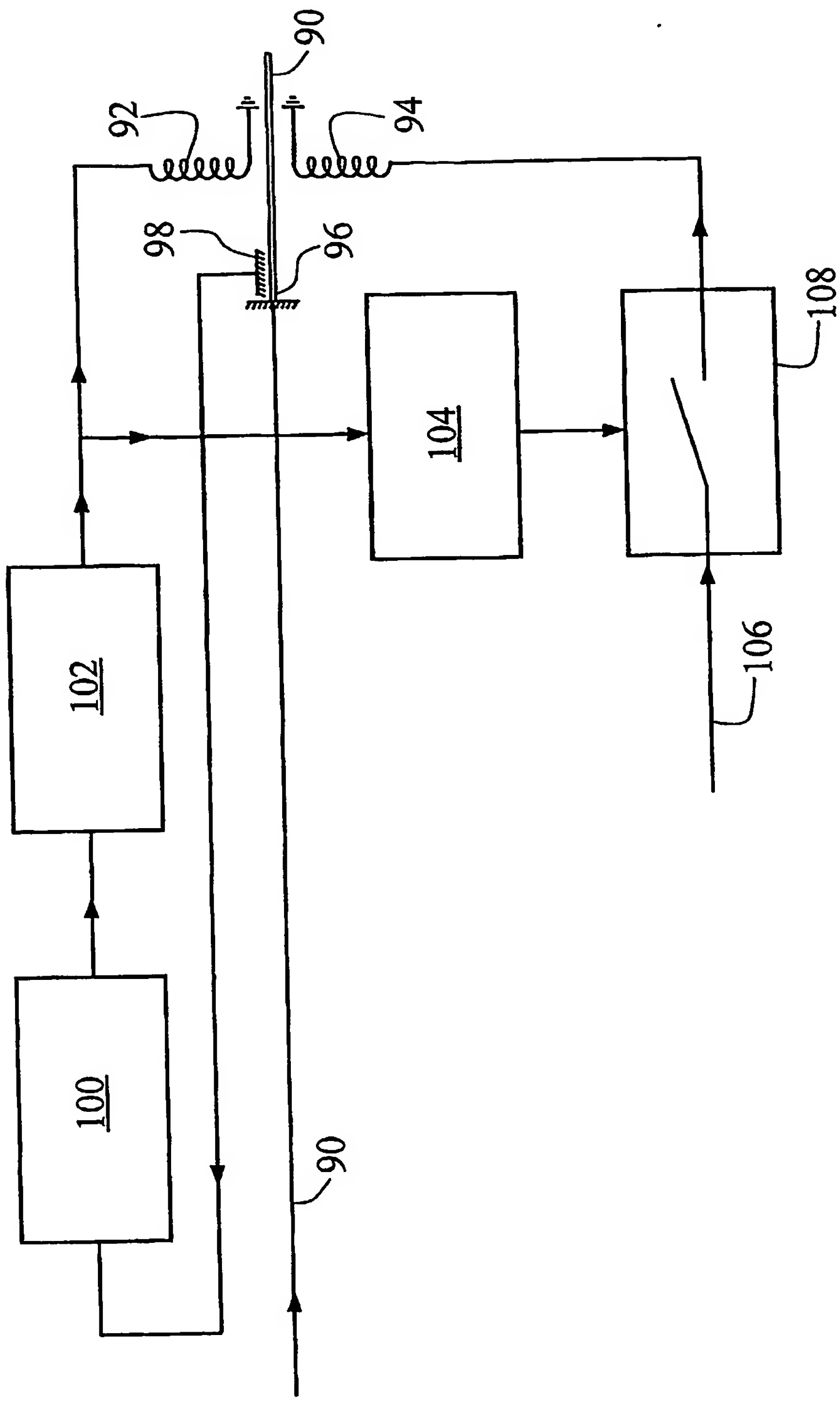

Figure 5